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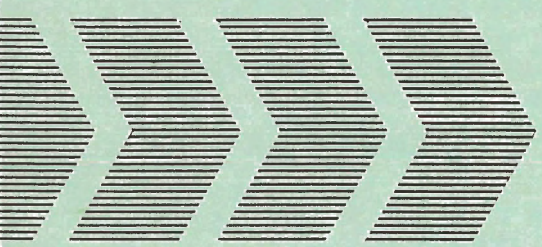
IMPACT of OFF-ROAD VEHICLE NOISE ON A NATIONAL FOREST

U. S. Department of Agriculture • Forest Service



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IMPACT OF OFF-ROAD VEHICLE NOISE ON A NATIONAL FOREST

by
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ED&T 2428
NOISE REDUCTION OF FOREST SERVICE EQUIPMENT

U. S. Department of Agriculture—Forest Service
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JULY 1975

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INTRODUCTION

This report presents the results of acoustical tests conducted by San Dimas Equipment Development Center (SDEDC) personnel on the Wayne-Hoosier National Forest, Eastern Region, the weekend of August 24 and 25, 1974, and the weekend of August 31 and September 1 and 2, 1974. This measurement program had two purposes; first, to determine how the ambient noise distribution in the immediate vicinity of proposed off-road vehicle (ORV) tracks is affected by the operation of jeeps and motorcycles along those tracks. Second, to determine how far, under normal forest conditions, these vehicles would be audible.

These two purposes demanded two distinct types of measurements. The first was to determine the effect on the ambient noise distribution in the area of the vehicle tracks; the second to ascertain detectability distance.

TEST SITES

The test site was selected by Forest personnel to adequately represent typical trail and vehicle operating conditions. All tests were conducted on the Wayne-Hoosier National Forest, Brownstown Ranger District, Range 1 East Township 7 North (Brownstown, Ind. 47220). Site 1, located in Section 20 approximately one-eighth mile south of Road 1575 on trail A; and site 2 also in Section 20, approximately one-quarter mile south of Road 1575 on trail C, represent areas in which typical ORV operation would be expected. Site 3, located on Road 1583 in Section 31 at the turnaround at the end of trail B, represents an area conducive to louder ORV operation since it is located on a steep hill. Site 4, in Township 36 at the end of the county road, was used for background measurements only. This site was included because of its proximity to the State Highway 446.

Jeeps approaching site 1 are shown in figure 1.

Figure 1. Jeeps at test site 1.

EFFECT OF ORV's ON AMBIENT NOISE DISTRIBUTION

Test Instrumentation and Methods

Instrumentation

B&K type 166 environmental noise monitors were used to gather the data. Two were placed at separate locations at sites 1 and 2. At sites 3 and 4 both monitors were used simultaneously in the same location. This provided for replication of data to help establish the overall accuracy of the experiment (see Accuracy of Data under Results and Interpretation).

The B&K type 166 environmental noise monitor is shown schematically in figure 2. It is actually a series of clocks, each of which is associated with an amplitude range; i.e., 35 to 37 dBA (decibels A-weighted), 37 to 40 dBA, etc. As the environmental noise level reaching the microphone rises to 35 dBA, the 35 to 37 dBA clock is turned on and runs. As the level reaches 37 dBA, this clock is deactivated and the next adjacent higher clock is activated. In this way a histogram of the sound level exposure that the microphone experiences is recorded. The data thus gathered were used to calculate the statistical noise parameters, L_1, L_{10}, L_{50}, L_{90}.

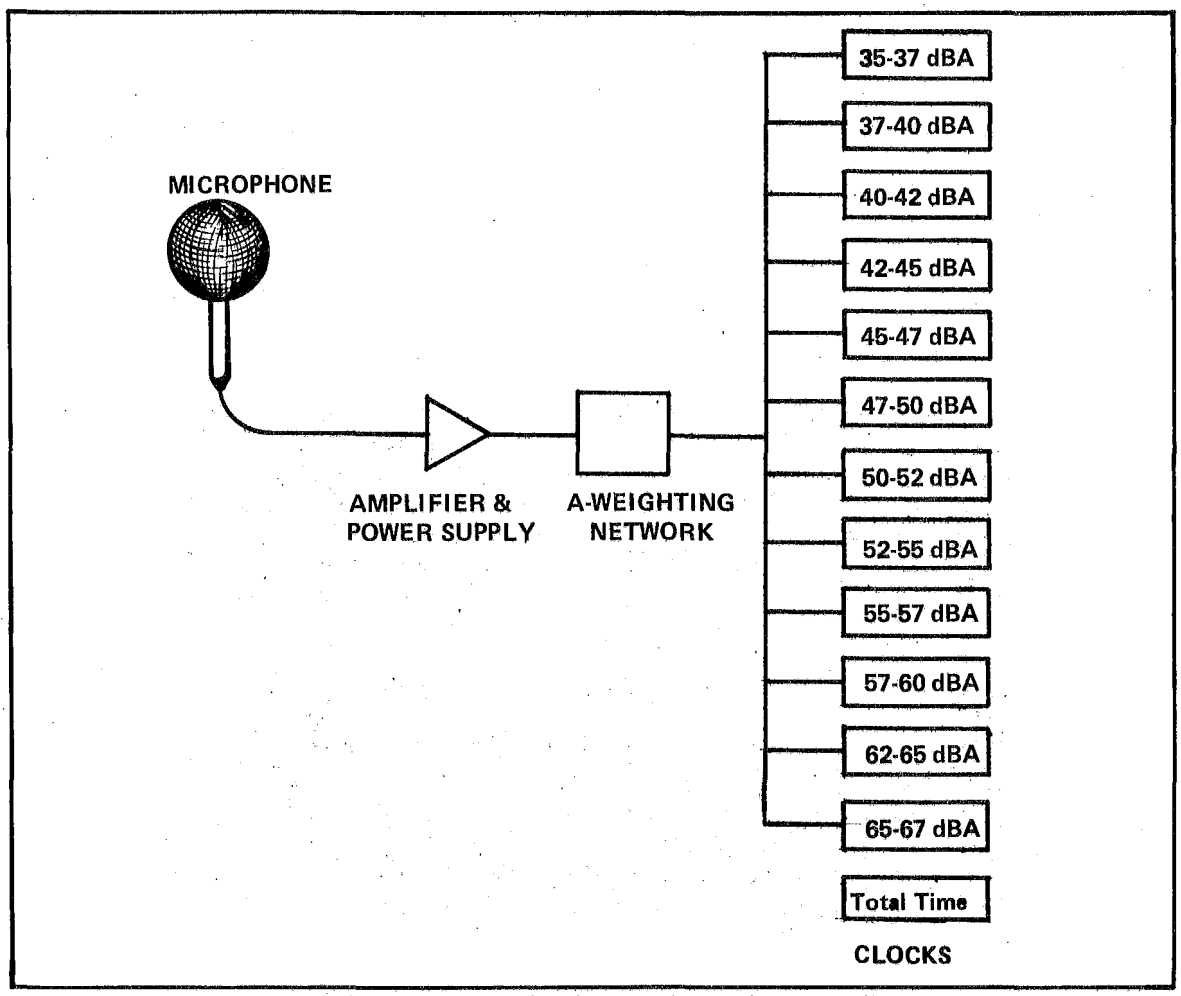

Figure 2. Environmental noise monitor schematic diagram.

Test Procedure

On the first weekend of the tests, measurements of the background noise without the presence of any ORV's were made at each of the test sites. On the next weekend, measurements with jeeps present on the ORV trails were made at sites 1, 2, and 3, and with motorcycles present at site 1. Motorcycle data were taken at site 2 but were not included in the analysis because rain during the tests destroyed their validity.

The tests were conducted as follows: At each of the sites, instrumentation was calibrated and set up. A corps of volunteer ORV operators, previously recruited by the Forest, started driving their vehicles back and forth on the ORV trail over a course, having a length of about three-eighths mile, that was adjacent to the instrumentation. This admittedly simulated situation provided extremely high traffic counts, probably in excess of anything that would be obtained under normal recreational ORV usage. The traffic counts, which ranged from 94 to 204 vehicles per hour, are dealt with later under Results and Interpretation. Normal ORV recreational operation technique was asked for and, we believe, obtained. All vehicles used were equipped with mufflers which meet the standards proposed to the Wayne-Hoosier by SDEDC. Both jeeps and motorcycles used during the test are probably representative of the ORV population that normally uses the Wayne-Hoosier.

Results and Interpretation

Table 1 shows the results of the noise distribution data gathered. The levels shown are L_1, L_{10}, L_{50}, and L_{90}. Traffic densities shown are in terms of vehicles per hour; distances are feet from the point of closest approach between the vehicles and the instrumentation. Under "Motorcycle Levels," are indicated single and double track ORV trails. The only difference between these, for our present purposes, is their location.

The noise distribution data, shown in table 1, answer the question "how does the addition of ORV's to the Forest acoustical environment affect that environment in the immediate vicinity of ORV trails?" It does not deal with the audibility distance of the ORV's. This question is taken up in a later section. The noise distribution data represent physical measurements; that is, they are measurements of sound pressure level, weighted by the A scale. An increase in sound pressure level does not necessarily connote a corresponding increase in annoyance or any other adverse reaction, as physical measurements cannot include an assessment of the attitudes of the listener. Listener attitude is the most important parameter in the determination of annoyance under forest conditions.

Explanation of the Levels

The subscript for each of the levels represents the percentage of time that the level indicated is exceeded; i.e., L_1 is exceeded only 1 percent of the time and may be considered to be the "very infrequent intrusion" level. For all practical purposes, L_1 is the maximum level *ever* experienced at a given site under given conditions. L_{10} is the level exceeded only 10 percent of the time, the "occasional intrusion" level. L_{50} is, of course, the median level. In other words, half the time it is louder than this, and half the time it is quieter. L_{90} could be considered the floor level as this is the level that is exceeded 90 percent of the time. It is of limited use to this study.

Table 1. Noise Distribution Data

BACKGROUND LEVELS (dBA)

Site-Loc. / Level	1-1	1-2	2-1	2-2	3	4	Avg-σ x 3
L_1	54	52	51	53	57	57	54.0–2.5
L_{10}	51	48	44	47	52	53	49.2–3.4
L_{50}	49	44	34	40	46	49	43.7–5.8
L_{90}	45	39	25	32	40	44	37.5–7.7

JEEP LEVELS (dBA)

Traffic Count / Distance (ft)	96 / 50	178 / 50	96 / 100	178 / 100	94 / 100	96 / 100	94 / 250	96 / 250	140 / 150
Site-Loc. / Level	1-1	1-1	1-2	1-2	2-1	2-1	2-2	2-2	3
L_1	61	64	59	60	58	59	53	53	61
L_{10}	56	60	53	55	53	52	50	50	56
L_{50}	51	55	46	47	46	43	45	47	51
L_{90}	45	49	39	40	40	34	43	40	46

MOTORCYCLE LEVELS (dBA)

Traffic Count / Distance(ft)	108 / 140	108 / 100	204 / 100
Site-Loc. / Level	1-1 SINGLE TRACK	1-2 SINGLE TRACK	1-2 DOUBLE TRACK
L_1	68	66	65
L_{10}	58	60	58
L_{50}	46	53	49
L_{90}	34	46	40

Accuracy of the Data

The accuracy of the instrumentation system was determined by field and laboratory tests to be better than $\pm$ 1 dB. Simultaneous measurements at as close to the same location as practical; that is, microphones of different instruments located about 4 feet apart; and at different times for the background level at the same location, are shown in table 2.

There are many reasons for the variations observed. Probably the greatest has to do with the insect population on the Forest. Large flies buzz by the microphone quite randomly. This probably controls the L_1 and L_{10} figures. Insect sounds are always present and control the entire background picture.

Table 2. Replicated Measurements

BACKGROUND LEVELS (dBA)						
LEVEL	Site 3–SIMULTANEOUS RUNS		Site 1, Location 1–SERIAL RUNS		Site 1, Location 2–SERIAL RUNS	
L_1	56	58	55	52	52	51
L_{10}	51	53	52	50	49	47
L_{50}	46	46	48	49	45	42
L_{90}	41	39	45	45	41	37

Another source of inaccuracy is the necessary assumption that the noise levels are normally distributed (Gaussian) in time. The correlation between a perfect normal distribution and the distribution seen for each site and location was better than 0.89. However, because of the limited length of the data taking period, not enough data were recorded near the ends of the distribution (L_1 and L_{90}) to prevent a certain amount of scatter. In general, the overall accuracy of the experiment could be said to be about $\pm$ 2 dBA. This means that if the difference between a background level at a site and the level at the same site with vehicles present is 4 dB or more, the difference is probably real, and not an artifact of inaccuracies in the experiment.

Interpretations of the Results

The background levels are shown on the top block of table 1, and presented for easier interpretation in table 2. The first table 2 entry shows simultaneous runs with parallel instrumentation at site 3. Note that there is, at most, a 2-dB discrepancy in the levels measured. The second and third entries show serial runs with the same instrumentation at site 1. The maximum discrepancy here exceeds 3 dBA only once. These measurements would seem to corroborate the statements made under Accuracy of the Data, regarding overall accuracy of the experiment.

Table 3, using data taken directly from table 1, displays the increase over the natural background noise effected by the addition of jeep noise to the Forest acoustic environment. At 50 feet, an increase in L_1, L_{10}, L_{50}, and L_{90} of 9 dB is seen. This increase

drops to an average of 3 dB at 100 feet and to a negligible increase at 250 feet. The 150-foot (site 3) data shown separately in table 3 are not directly comparable to those for other distances. The site 3 data were taken under conditions at maximum performance; that is, the jeeps were climbing a steep hill at full throttle. If vehicle operation at site 3 had been normal, the increase over average background levels would be expected to be about 2 or 3 dB. Instead, as seen in table 3, they are about 7 dB. This leads to the interpretation that at maximum performance, a jeep's contribution to the overall acoustical environment will be about 5 dB greater than its contribution under normal performance. By implication, this means that the noise-affected zone will be about twice as wide.

Table 3. Increase over Background Noise Distribution caused by Jeeps and Motorcycles

JEEPS, NORMAL OPERATION				
LEVEL	AVERAGE BACKGROUND	AVERAGE INCREASE, dBA		
		50 FT	100 FT	250 FT
L_1	54	9	5	-1
L_{10}	49	9	4	1
L_{50}	44	9	2	2
L_{90}	38	9	0	4

JEEPS, SEVERE OPERATION		*MOTORCYCLES*		
LEVEL	150 FT	LEVEL	100 FT	140 FT
L_1	7	L_1	12	14
L_{10}	7	L_{10}	10	9
L_{50}	7	L_{50}	7	2
L_{90}	9	L_{90}	5	-4

Increases caused by the motorcycles, at 100 and 140 feet, are also shown in table 3. These increases are considerably higher than those for jeeps. In addition, the increases are greatest at L_1 and decrease through L_{10}, L_{50}, and L_{90}. There are two predominant reasons for the increases being greater at a distance of 100 feet for the motorcycles than for the jeeps. One is that the motorcycles are slightly louder under maximum noise conditions than are the jeeps. In addition, the frequency content of their noise is somewhat different; this is dealt with at more length under ORV Detectability Distance. The second reason is that motorcycles are normally operated closer to their maximum noise potential than are jeeps. Thus, it could be expected that the noise-affected zone would be somewhat wider for a motorcycle operation than for normal jeep operation, but probably of about the same extent of the noise-affected zone created by maximum performance jeep operations.

The explanation for the site 3 jeep data also applies to the 140-foot motorcycle data. The 100- and 140-foot data were taken at different sites and the negotiation of the site where the 140-foot data were taken demanded wide throttle settings and higher rpm; in other words, higher performance all around, thus more noise at the source.

Effect of Traffic Volume

Table 4 shows the effect of traffic volume. On the average, it is seen that roughly doubling the volume from 96 vehicles per hour to 178 vehicles per hour results in an increase in all measured levels of about 2 or 3 dB on the average. If each vehicle were functioning as a point source, doubling the volume would add 3 dB. However, because of the close proximity of the vehicles at this traffic rate, each vehicle would not be expected to act as a point source and the average measured values are in good accord with what would be predicted theoretically. One hundred seventy-eight jeeps per hour is very heavy traffic on this type of road, probably close to the maximum that this road could sustain.

Table 4. Effect of Traffic Volume

JEEP LEVELS (dBA)						
	SITE 1, LOCATION 1			SITE 1, LOCATION 2		
LEVEL	96 VEH/HR	178 VEH/HR	DIFF.	96 VEH/HR	178 VEH/HR	DIFF.
L_1	61	64	3	59	60	1
L_{10}	56	60	4	53	55	2
L_{50}	51	55	4	46	47	1
L_{90}	45	49	4	39	40	1

Conclusions

From the data presented, the following is concluded:

1. The noise-affected zone, caused by the expected range of jeep operations on the Wayne-Hoosier, ranges approximately from 250 to 500 feet on either side of the track. This only means that there is a measureable increase in the background noise for this distance from the vehicle track. It does not mean that the vehicles will not be audible beyond this distance.

2. For motorcycles, the noise-affected zone is approximately twice as wide.

ORV DETECTABILITY DISTANCE

The preceding material dealt with the ambient noise distribution in the immediate vicinity of proposed ORV tracks and how this distribution is affected by motorcycle and jeep operation along the tracks. The material that follows presents the results of tests run to determine how far the vehicles would be audible.

Test Instrumentation and Methods

High quality portable tape recorders were used to gather the acoustic data for this portion of the test. The tape recorders were run simultaneously with and placed in the same location as the B&K type 166 environmental noise monitors described in the preceding test discussion.

The data were reduced by the acoustical consulting firm of Bolt Beranek and Newman, Canoga Park, Calif., using their real-time octave band analyzer and dedicated computer. This system provided a data matrix which displayed the measurements taken at each data gathering location distributed in both time and frequency domains. Details of this method of handling the data are given in the appendix. The method of Fidell, Pearsons, and Bennett (Bolt Beranek and Newman Technical Report 2202, July 1972) was then used to further reduce these data to detectability distances. This is also discussed in the appendix.

The vehicle operation procedures given in the preceding material were, of course, used to develop these data, which were gathered simultaneously with the noise distribution data as already described.

Results and Interpretation

Without explanation of how they were developed, a summary of the results is presented in table 5. A more detailed presentation of the results, along with a step-by-step explanation of the methods used to develop them, is given in the appendix.

Table 5. Summary of Results

AVERAGE FOREST CONDITIONS						
		Percent of Vehicles Present, Detected at Distance Shown (Ft)				
SITE	VEHICLE TYPE	500	1,000	2,000	4,000	8,000
1	Jeep	25	8	1	almost none	almost none
2	Jeep	25	8	1	almost none	almost none
3	Jeep	most	most	10	3/4	almost none
1	Motorcycle	27	20	9	1	almost none
QUIET FOREST CONDITIONS						
		Percent of Vehicles Present, Detected at Distance Shown (Ft)				
SITE	VEHICLE TYPE	500	1,000	2,000	4,000	8,000
1	Jeep	most	30	11	1	almost none
2	Jeep	most	30	11	1	almost none
3	Jeep	most	most	25	5	1/2
1	Motorcycle	30	27	20	8	almost none

"Average Forest Conditions" implies that no more than 50 percent of all possible listener locations, no more than the percentage of vehicles shown would be detected; i.e., under level ground operating conditions, no more than 8 percent of the jeeps traveling on the vehicle track would be detected at more than half of the possible listener locations farther than 1,000 feet from the closest approach of the vehicle.

"Quiet Forest Conditions" could be expected to occur at approximately 16 percent of the possible listener locations. From this part of table 5, we see that at no more than 16 percent of the possible listener locations 1,000 feet from the vehicle would more than 30 percent of the jeeps be detected.

Note that a higher percentage of jeeps are heard at site 3 than at sites 1 and 2. This is because at site 3 the vehicle track is located on a quite steep hill, demanding wide-open throttle, whereas at sites 1 and 2 more normal, flat-ground operation was appropriate.

Motorcycles, being louder than jeeps, are more readily detected at any given distance. Also, motorcycles are usually operated at higher throttle settings than jeeps, regardless of gradient, so their detectability distance varies less than that of jeeps as a function of gradient. There are no significant differences other than gradient between sites 1 and 2 and site 3.

A different method of data presentation is shown in table 6. Table 6 shows for "average" and "quiet" listener locations, the distances for which 25, 5 and ½ percent of the vehicles would be detected. For all practical purposes, the ½ percent detectability distance could be considered the distance at which the vehicles are not ever audible. Under "freak" conditions of very low background noise, downwind sound propagation, etc., it is possible that these detectability distances would be exceeded. This is, however, statistically quite unlikely. The longest distance shown (7,900 feet for jeeps under hill-climbing conditions being listened for from a "quiet" location) is greater than the maximum detectability distance ever observed under any conditions by the author.

The last column in table 6, the ½ percent detectability distances with the listener under "quiet" conditions, is interpreted that at only 16 percent of the possible listener locations at the distances shown would an observer hear more than one out of every 200 vehicles. For maximum traffic counts possible on the vehicle tracks on the Wayne-Hoosier, this would be less than one noise intrusion, barely detectable, per hour.

Now look at the fourth column in table 6. This indicates that at a distance of about ½ mile or less under average forest background conditions, about 5 percent of the vehicles present would be barely detected. It does not mean that vehicle noise would be present 5 percent of the time. It does mean that, at the distance shown, if 50 vehicles per hour travel the vehicle track, at about ½ mile away under average forest background noise conditions the average observer would barely detect two or three vehicles per hour. It is not likely that the duration of the signal which the observer detects would be greater than 1 or 2 seconds at the most.

Conclusions

From the detectability data presented, the following is concluded:

1. At the average listener location, no more than 5 percent of the vehicles on an ORV

track will be detected at distances equal to or greater than ½ mile from the vehicle track.

2. For all practical purposes, in the forest conditions presented by the Wayne-Hoosier National Forest, the maximum distance at which a vehicle may be heard ranges from approximately 4,500 feet for jeeps operated on level ground to approximately 7,500 feet for hill-climbing jeeps and motorcycles.

Table 6. Detectability Distance (ft)

SITE	VEHICLE	"AVERAGE" LISTENER LOCATION			"QUIET" LISTENER LOCATION		
		25% DET.	5% DET.	½% DET.	25% DET.	5% DET.	½% DET.
1 (Level ground performance)	Jeep	500	1,300	2,200	600	2,900	4,800
2 (Level ground performance)	Jeep	600	1,200	2,500	1,200	2,300	5,200
3 (Hill climbing)	Jeep	1,700	2,300	4,800	2,000	4,100	7,900
1	Motorcycle	700	2,600	4,400	1,300	4,700	7,300

APPENDIX

Introduction

This appendix is designed to do two things. Its primary goal is an in-depth presentation of the aural detectability distance data gathered on the Wayne-Hoosier National Forest and the results calculated therefrom, and to present an explanation and interpretation of the data. However, because of the highly technical nature of these data and how they were handled, I feel a necessary secondary goal is to lead you step-by-step through not only how I have handled and presented the data, but also through a step-by-step explanation of the basics of how sound propagates, and is attenuated, through the Forest. I would suggest that you not undertake to read this appendix unless you have about 2 uninterrupted hours to lock yourself away. I would also suggest that you have available Beranek's book "Noise Reduction" (McGraw Hill 1960) or Harris' "Handbook of Noise Control" (McGraw Hill 1957), or failing one of these, the General Radio "Handbook of Noise Measurement" (General Radio Co., West Concord, Mass).

How Sound Attenuates

Spherical Divergence

Picture a perfectly flat homogeneous world. It has air and soft, absorbent ground but not much else; no trees, no hills, no motorcycles. A man is standing at ground zero, blowing a whistle. You and your sound level meter are walking away from him in a straight line. At a distance of 10 feet, you hear his whistle and he's making 100 decibels (dB). At 20 feet, you measure again and find he is making 6 less, 94. At 40 feet you once again measure 6 less dB and so on; a drop of 6 dB for each doubling of distance. This phenomenon (common to radio and water waves as well as sound waves) is known as spherical divergence. We express it mathematically by equation 1.

(1) $$L_X = L_O - 20 \log \frac{R_X}{R_O}$$

where L_X = the level in decibels at distance x

L_O = the level at some other distance (in our case, 10 ft)

R_X = the distance from the source at which L_X is measured

R_O = the distance from the source at which L_O is measured.

Absorption in Air

Now as you further walk away from this whistling man, you see that the level begins to drop faster than predicted by equation 1. Further, you observe that his whistle seems to change pitch (or frequency).

This is because sound is absorbed by molecular action in air. At shorter distances (up to several hundred feet for practical purposes) absorption does not matter. However, at longer distances, it becomes the overwhelming consideration, far outweighing the spherical divergence described by equation 1. It is important to remember that this absorption varies as a function of frequency (thus the apparent change in pitch). It also varies in a real atmosphere as a function of temperature, relative humidity, wind movement, vertical thermal and density gradients, scale of turbulence, and a number of other factors which may include your age and Social Security number and the phase of the moon as far as is known to acoustical science.

Our equation 1 now becomes equation 2, where L_X, L_O, R_X, and R_O are described above and $\triangle$ = the absorption in air of the sound energy in terms of decibels per foot. Remember $\triangle$ changes as a function of frequency.

(2) $$L_X = L_O - 20 \log \frac{R_X}{R_O} - (R_X - R_O)\,(\triangle)$$

Other Factors

Now, we will add trees, rocks, dirt, landforms, shrubs, and grasses (but no motorcycles yet) to our flat world. All these artifacts affect the transmission of noise through mechanisms much too complicated to discuss here. However, the effect tends to be constant at distances greater than 500 feet, even though it somewhat varies with frequency. In other words, all the screening provided by the trees and rocks, etc., generally is provided within the first 500 feet. At distances greater than that the sound merely propagated above the trees. We'll call this added attenuation "terrain loss" T; and to be more accurate, we might tack on a minus T behind equation 2. T affects mostly the lower frequencies, ranging from 14 dB at 250 Hz to about 9 dB at 1,000 Hz and 0 above that, under conditions encountered on the Wayne-Hoosier.

So, now we know how a noise attenuates or is reduced as a function of distance from the source. If we keep in mind that the noises with which we are dealing, jeep and motorcycle sounds, are merely a summed collection of pure tones, each of which can be handled one

at a time, we will see that the spectrum of a motorcycle noise (its frequency versus amplitude chart or noise signature) changes as a function of distance from source to receiver. Figure A-1 shows a set of spectra for a motorcycle at distances of 500, 1,000, 2,000, 4,000 and 8,000 feet. Also, shown for reference's sake is the spectrum at 50 feet. This motorcycle just meets the criterion of 82 dBA at 50 feet (measured by SAE J331a) currently adhered to by Motorcycle Industry Council members. Note that the spectra are not parallel because of different atmospheric attenuations and T's at different frequencies. Levels at frequencies above 1,000 Hz drop off more rapidly for distances of greater than 500 feet. However, at shorter distances, the greater effect of T causes more drop in the lower and middle frequencies.

How Sound is Detected Under Forest Conditions

In a Quiet World

Up to this point, if you will recall, we have had a perfectly quiet world except for our man blowing his whistle. No birds or insects break the stillness at your ear. For our present purposes, we will keep it that way.

Figure A-2 shows the lowest level of sound that you can hear as a function of frequency. Another way to say this is that at lower frequencies, you don't hear as well as you do at frequencies between 1,000 and 4,000 Hz. At higher frequencies, your hearing also tails off. So if our whistling man is whistling in the 125- to 250-Hz octave, he would have to whistle about 18 dB (at your ear) for you to hear him. However, if his whistle were tuned to the 4,000- to 8,000-Hz octave, he could probably whistle at only about 5 dB and you would hear him fine. Now, remembering that a motorcycle noise is just a collection of single frequency whistles, let's plot the 8,000-foot spectrum from figure 1 on figure A-2, and call it figure A-3. If any part of the motorcycle spectrum is above the threshold-of-hearing line, you can detect that the motorcycle is there. Thus, we see that at 8,000 feet you will be easily able to detect the motorcycle.

In a Real (Noisy) World

To this point, we have had complete silence at the listener's position. We know this is not the case. Indeed, the spectrum of the background exceeded at 99 percent of the locations measured on the Wayne-Hoosier looks like that shown in figure A-4.

The way the human ear works, it needs a certain signal-to-noise ratio (that is, ratio of loudness of desired signal to loudness of background noise),before it will detect the desired (or undesired, maybe) signal. This complicated function is taken care of by "fudging in" a "slanted" set of grid-lines on figure A-3, and plotting the background spectrum using these new slanting grid-lines. If you need further details on this, consult B B&N Report No. 2202 by Fidel, Pearsons, and Bennett. In any event, figure A-5 shows the spectrum of A-4 superimposed on figure A-3. If a spectrum or noise signature falls entirely within the area contained underneath the hearing threshold line and the background spectrum line (shaded in A-5), then it won't be detectable. In our example, since the "8,000-foot spectrum" is entirely below the threshold and background spectrum, the motorcycle will not be detectable. As the source and the listener move closer together, the spectrum of the noise source moves up and when it just touches this line, it is just then detectable.

Figure A-5 embodies certain assumptions necessary to simplify this very complicated problem. One is that 50 percent of the signals actually present (just touching the line)

will be detected and 50 percent will not. Also, the chart embodies assumptions leading to a 1 percent false alarm rate. That is to say that 1 out of every 100 responses that a listener makes to a noise that he thinks he hears will be to a noise not there; i.e., a false alarm.

We have thus far assumed that each noise outburst is continuous and steady, and each burst has the same amplitude and spectral characteristics as all the others. This is anything but the case with motorcycles and jeeps. We have also assumed that all locations possess a uniform background noise signature and we know this not to be the case. For any given data-taking session (normally ½ hour long), no single number serves to describe either amplitude or frequency, but each of these quantities must be described as a distribution. Thus, the data for each data segment are best presented as a matrix, as shown in figure A-6. This represents a tape recording made of jeeps at site 2-2. The numbers shown in the body of the matrix are amplitude levels in decibels. The numbers across the top of the matrix are the octave bands of frequency; and the numbers in the column along the left edge are the "exceedence levels." In other words, for 99 percent of the time, the level in the 500-Hz octave band is 24.6 dB, or greater, in amplitude. For 50 percent of the time, it is 30 dB or greater, and for only 1 percent of the time does it exceed 41.7 dB.

To help conceptualize this idea, let us do away with our whistling man. We will instead run, right through the point where he was, an infinitely long acoustically lined concrete pipe, 10 feet in diameter, stretching from one horizon to the other. Our listener is at a given distance, perpendicular to the pipe, off in the Forest. Directly opposite his position, there is a 10-foot gap in the pipe. Motorcycles and jeeps drive down this pipe at speed. Because of the acoustical properties of the pipe, they emit no noise to the outside world until they pass the gap; they are there only for a very short time and then they are no longer heard from. (This is not a suggestion for a solution to the ORV noise problem on the Wayne-Hoosier.)

Now, if 100 jeeps zipped down the pipe in 1 hour, and our sound level meter at measuring site 2-2 were set up to read only 500-Hz octave band noise, 99 of these jeeps would make the sound level meter read 24.6 dB or above, 50 of them 30 dB or above, but only 1 would cause the sound level meter to read at or above 41.7 dB.

Now, if we look at the various locations available to listen to our jeeps going through the pipe, we will find that the background spectra vary considerably from site-to-site, as well as at the same site from minute-to-minute, and hour-to-hour. Our data gathering program attempted to sample enough of these background spectra to establish their distribution both in time and space. It was found that these background spectra follow the proverbial bell-shape curve; or more elegantly stated, are distributed in a Gaussian manner. So, while we can not say what the detectability distance of a given ORV noise signature will be at any given site, we can estimate what it will be statistically. For an example, go back to table 6 of the main body of this report; at the average, or 50th percentile, or mean listener location, we find we detect (just barely hear) 5 percent of the motorcycles at a distance of no more than 2,600 feet. This distance to detect 5 percent rises to 4,700 feet for a "quiet" listener location, one arbitrarily defined as quieter than all but 16 percent of all possible locations. Those of you with a statistical background have no doubt guessed that this is the one sigma or one standard deviation point. To escape detecting all but ½ of 1 percent of all the motorcycles at the quiet location, we must go 7,300 feet away. And so on.

Data Presentation Made Understandable

If you are still with me, by now you are no doubt wondering why I led you through this morass of acoustical statistics, as we have not yet seen any results. Results are presented in figures A-7 through A-9. Interpret the results thus:

1. You know the traffic rate, in terms of vehicles per hour (example—100 vehicles per hour) and how many acoustic intrusions you will permit per hour (example—1). You are interested in jeeps under steep gradient conditions. How far away must you stay to meet this detectability criterion at "average" and at "quiet" sites? First figure your detectability criterion (example 1 + 100 = 1 percent), then turn to figure A-8. Follow the dashed line from the 1 percent detectability criterion on the ordinate to the curve marked 50 percent. Drop to the abscissa and read 3,600 feet. This is the distance that must be maintained at average sites. Repeat to find the "quiet site" distance, using the curve marked 84 percent.

2. You know how far away the vehicle trail is (3,000 feet) and you know the traffic rate (100 vehicles per hour). How many motorcycles would be detected per hour at this distance at a "quiet" location? Go to figure A-9, enter at 3,000 feet on the abscissa, move up to the curve marked 84 percent and then left to the ordinate. The examples shows that at no more than 16 percent of the possible listener locations, 3,000 feet from the track, will you detect more than 13 percent, or 13 jeeps per hour. Interpolation is of course permitted, but remember that it must be done on a normal probablistic scale in reference to both the distance between the charted lines and on the ordinate. The abscissa is of course linear.

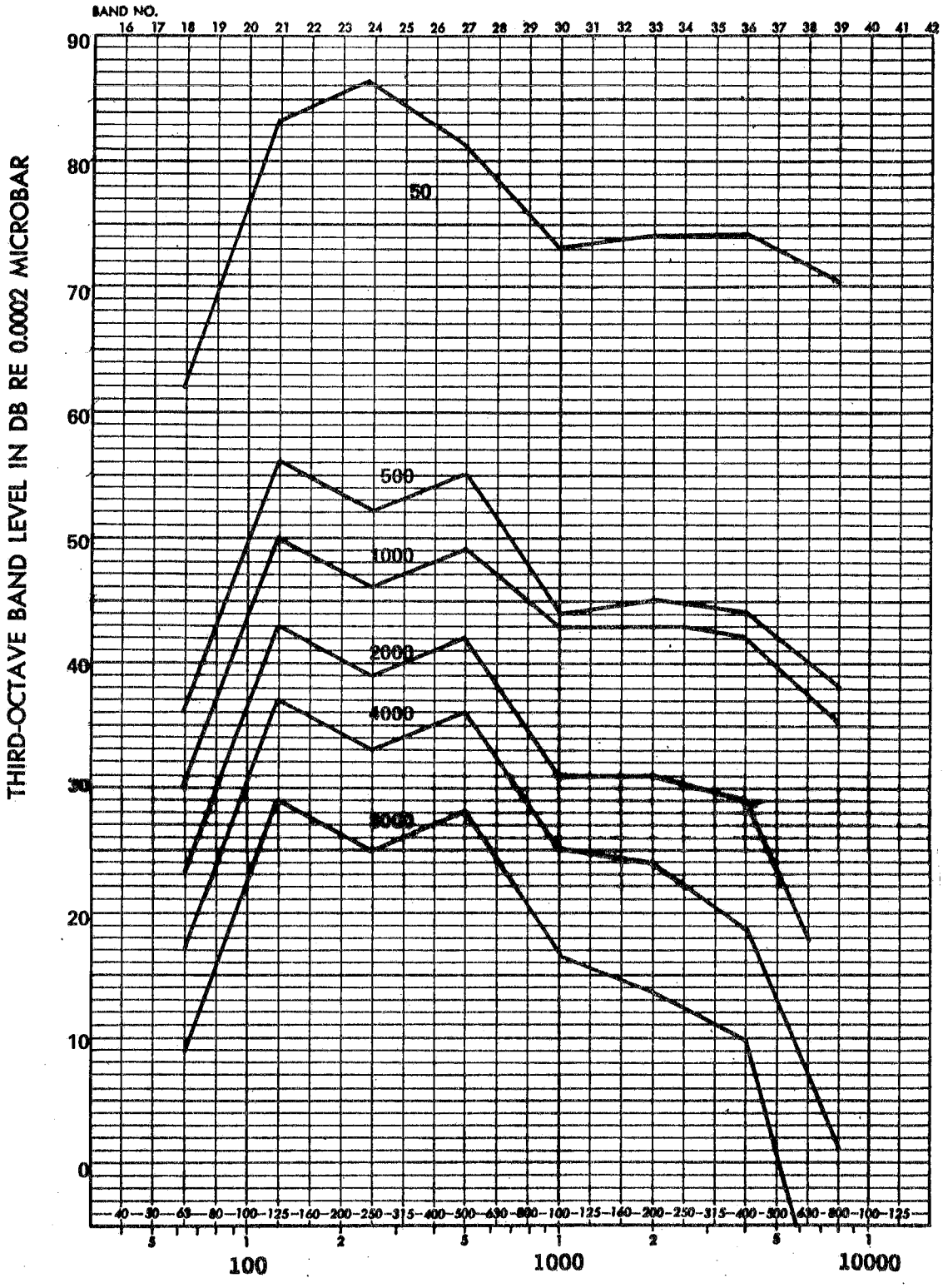

FIGURE A-1. SPECTRA OF MOTORCYCLE AT VARIOUS DISTANCES.

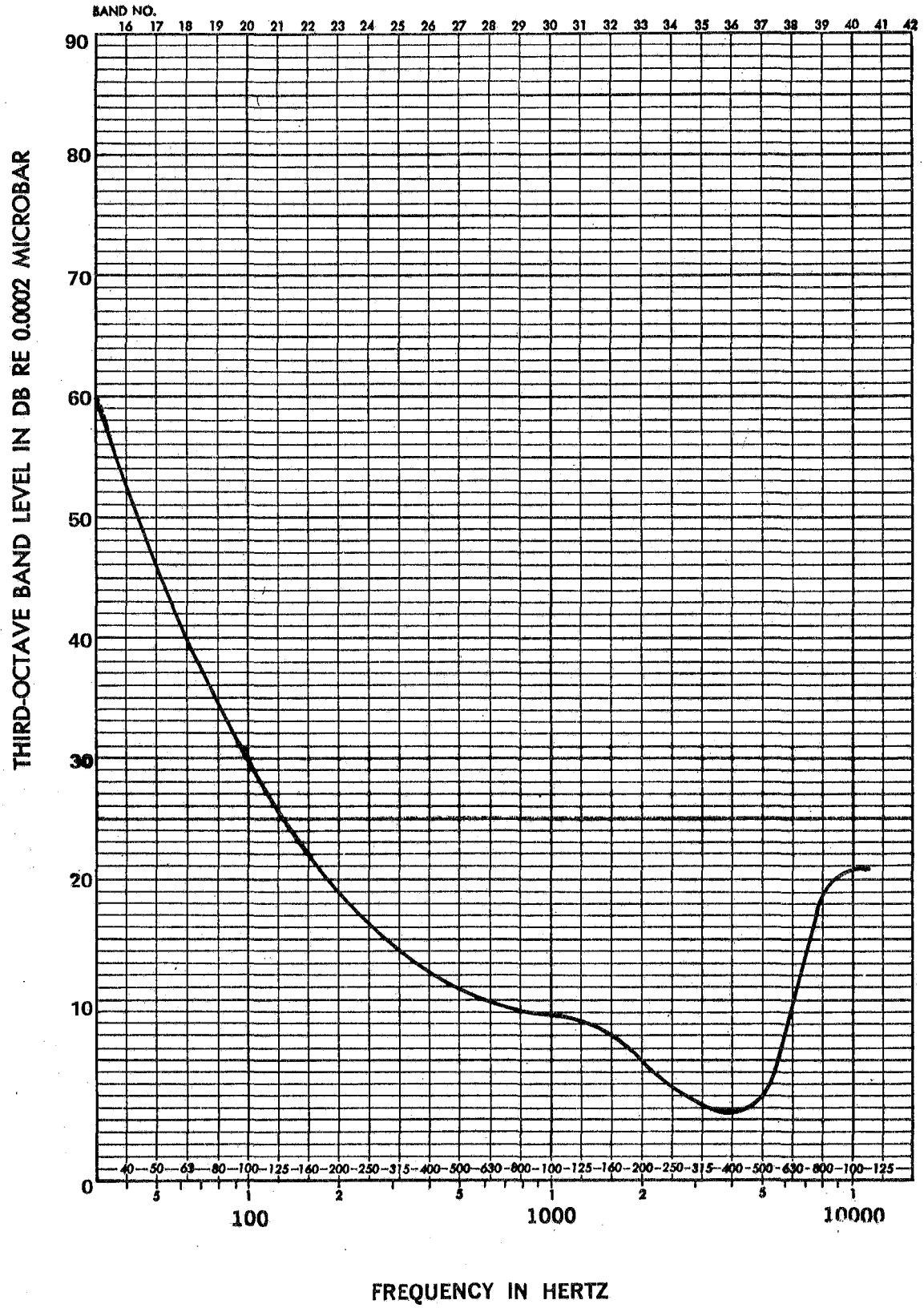

FIGURE A-2. HEARING THRESHOLD.

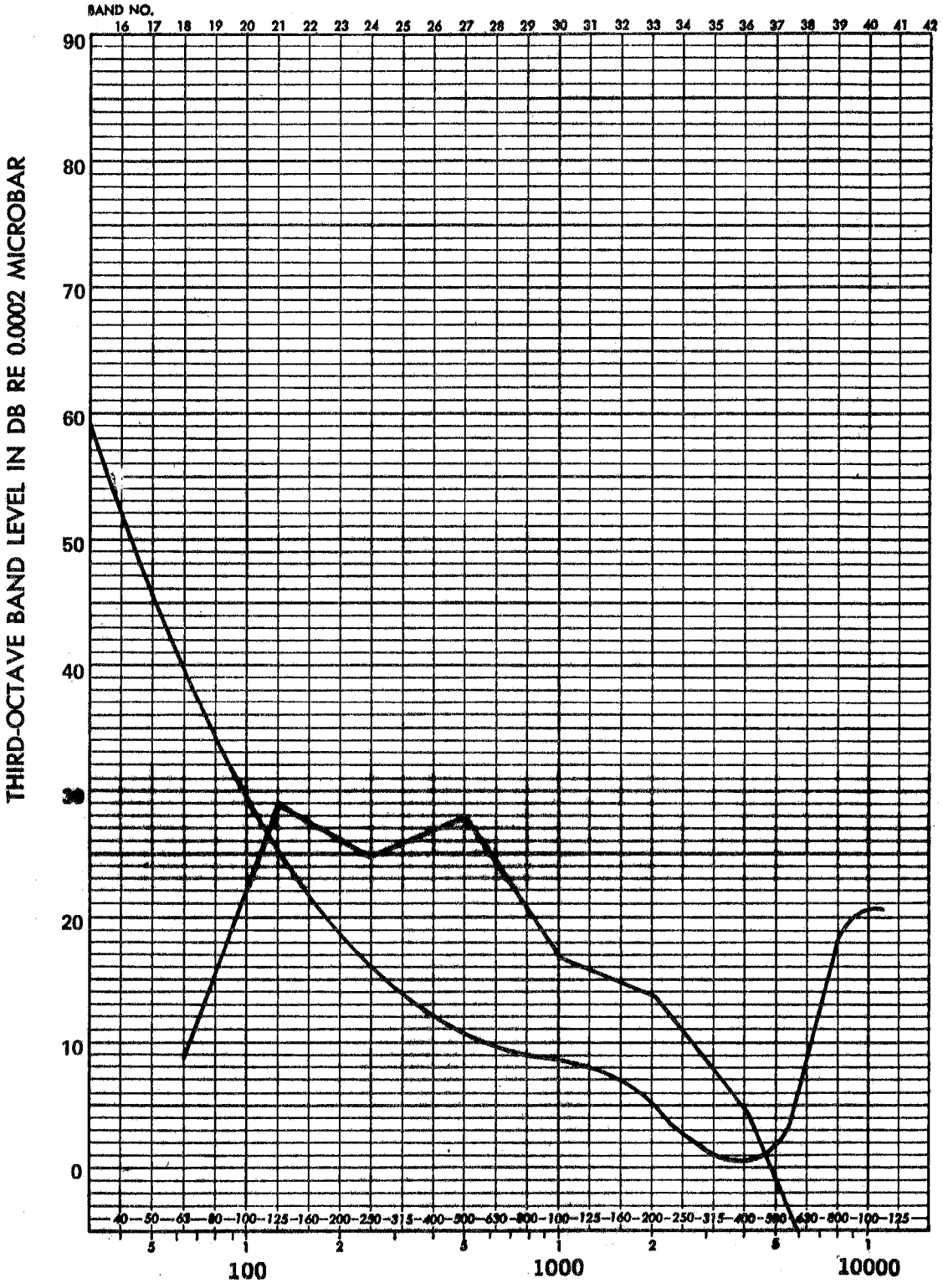

FIGURE A-3. 8000 FT SPECTRUM AND HEARING THRESHOLD.

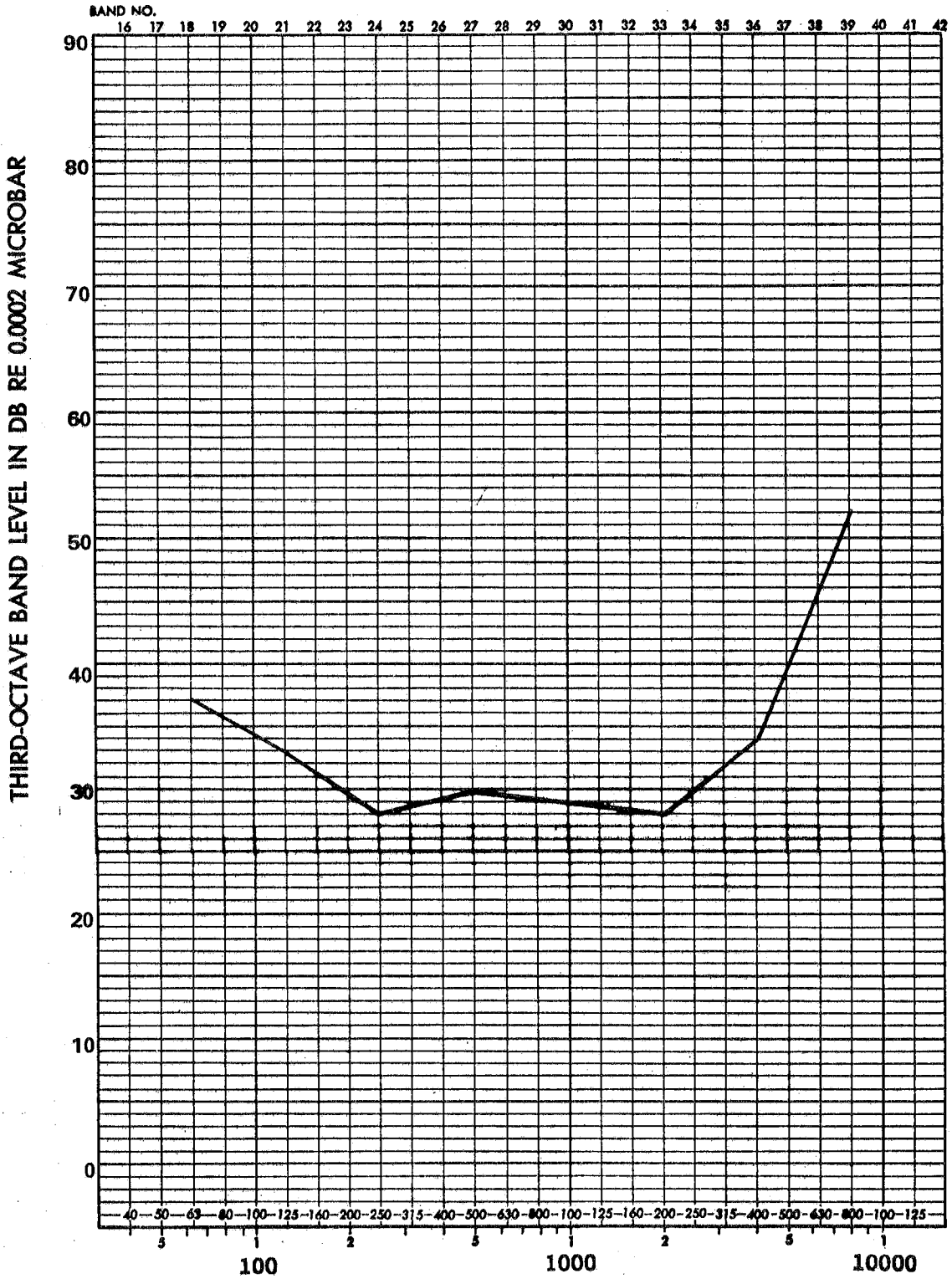

FIGURE A-4. BACKGROUND SPECTRUM.

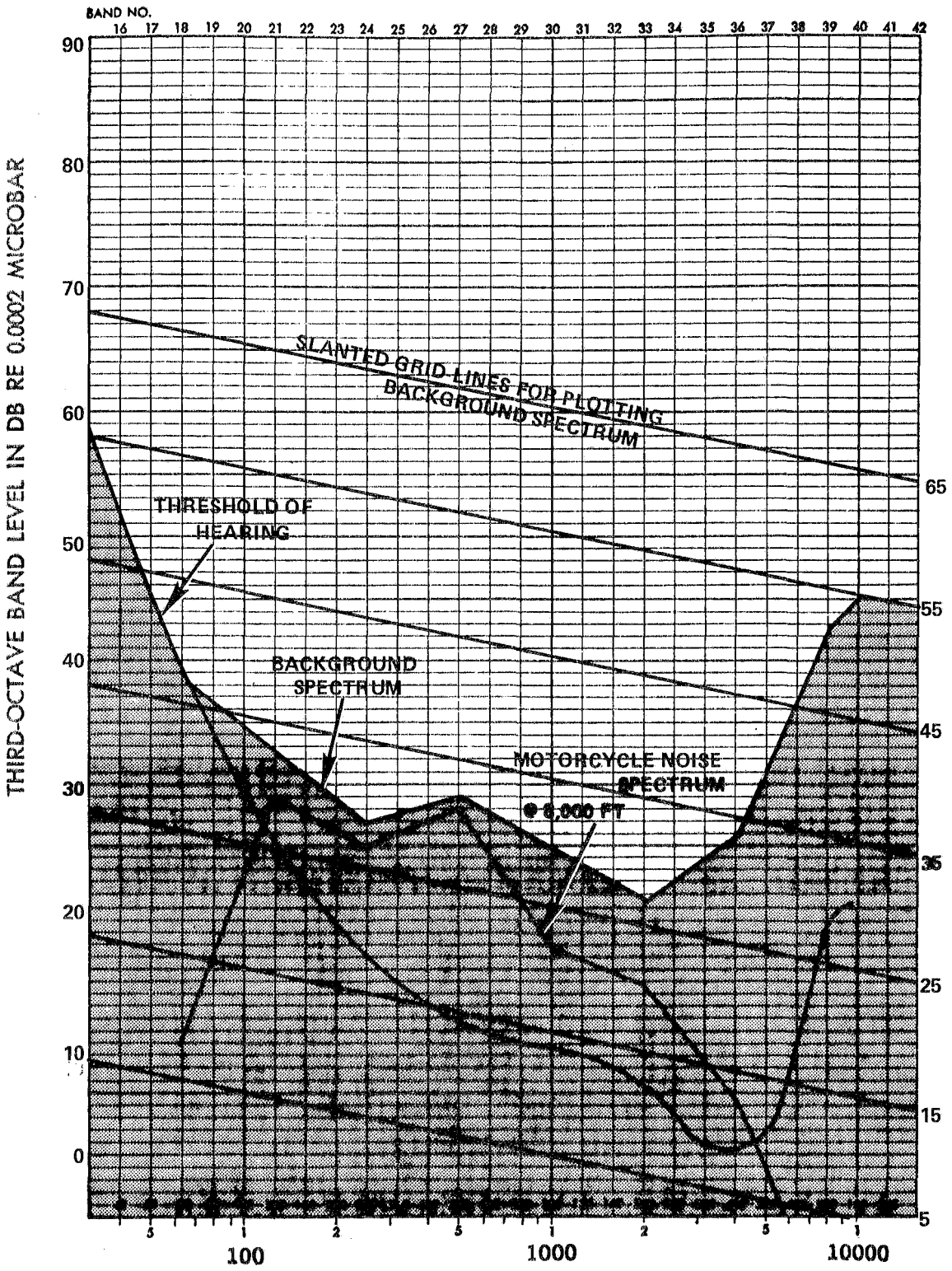

FIGURE A-5. DETECTABILITY CHART.

	63	125	250	500	1000	2000	4000	8000
99%	23.4	20.4	21.4	24.6	23.9	22.9	30.7	45.3
95%	24.6	22.4	22.4	25.9	25.1	24.7	32.3	45.9
90%	25.4	23.6	23.7	26.7	26.1	26.0	33.4	46.8
75%	28.9	25.8	25.6	28.4	28.0	28.2	35.8	48.0
50%	38.8	30.9	27.9	30.0	29.9	30.7	38.7	49.2
25%	44.0	39.8	30.5	32.3	32.1	32.8	41.7	50.5
10%	48.0	45.7	33.8	34.1	34.3	35.4	44.7	52.6
5%	50.9	50.9	36.9	36.2	36.4	37.1	46.6	54.4
1%	57.2	59.2	45.6	41.7	39.8	39.3	49.3	61.2

FIGURE A-6. SAMPLE DATA MATRIX.

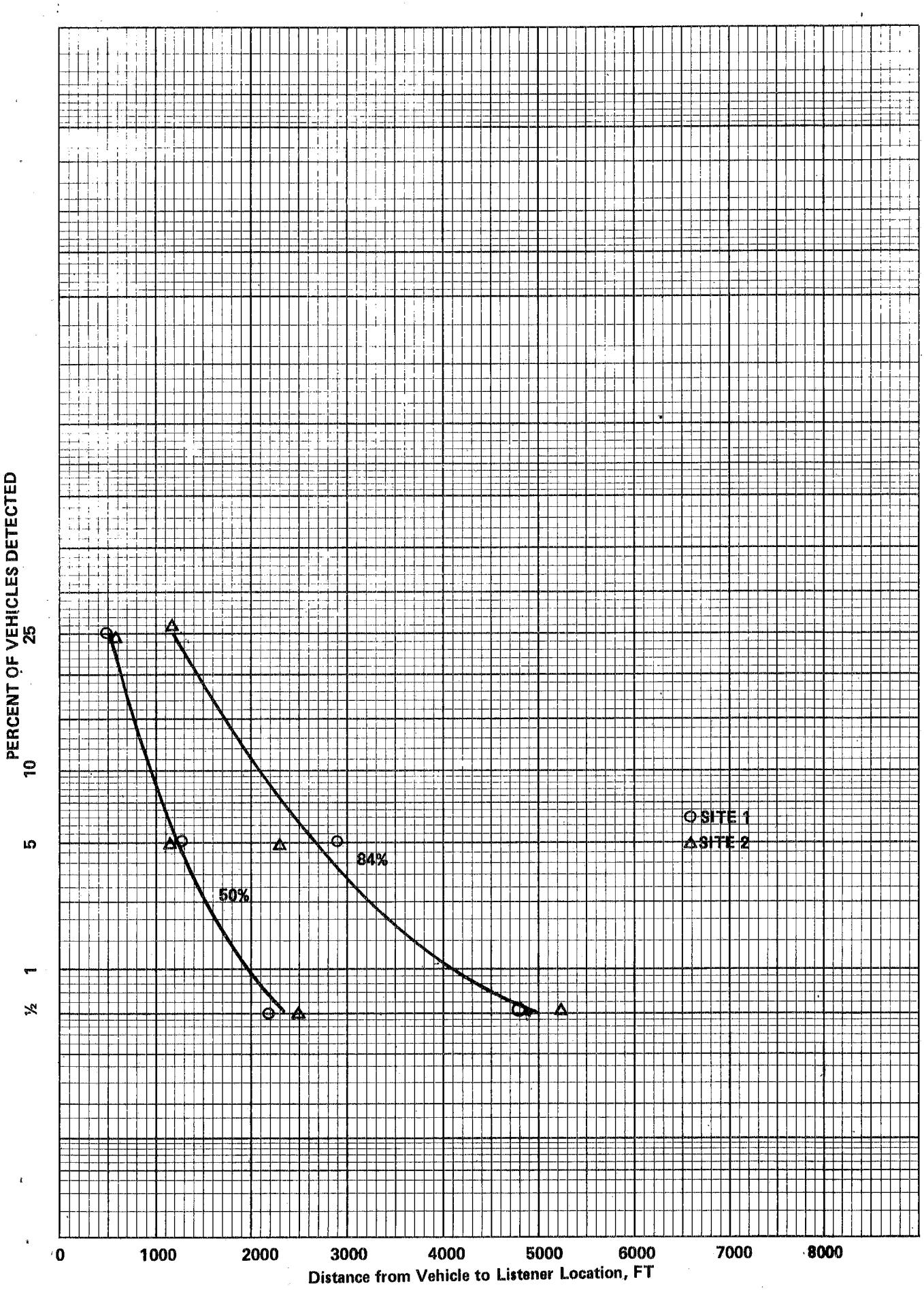

FIGURE A-7. DETECTABILITY—JEEPS—LEVEL GROUND PERFORMANCE.

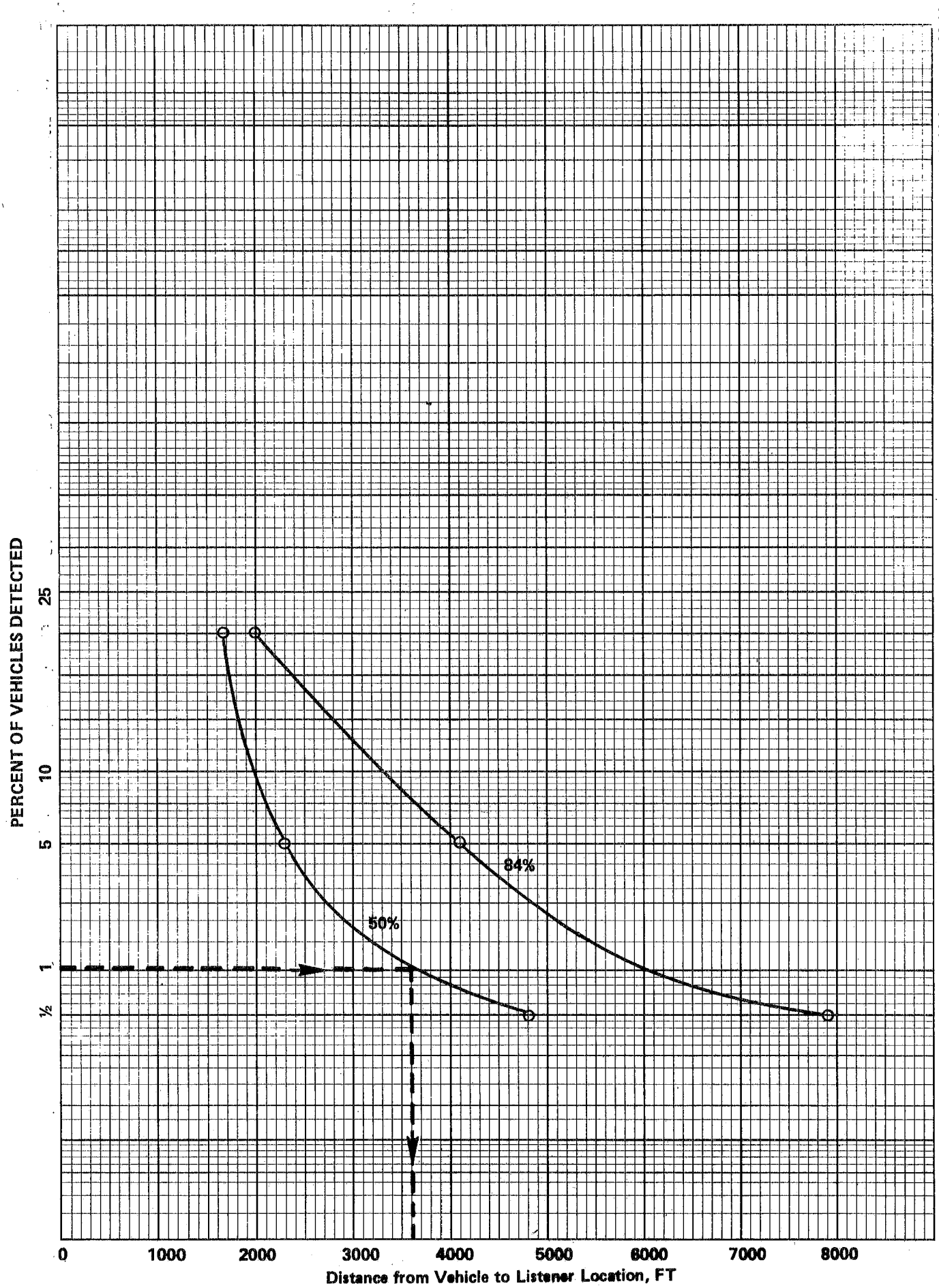

FIGURE A-8. DETECTABILITY--JEEPS--HILL-CLIMBING PERFORMANCE.

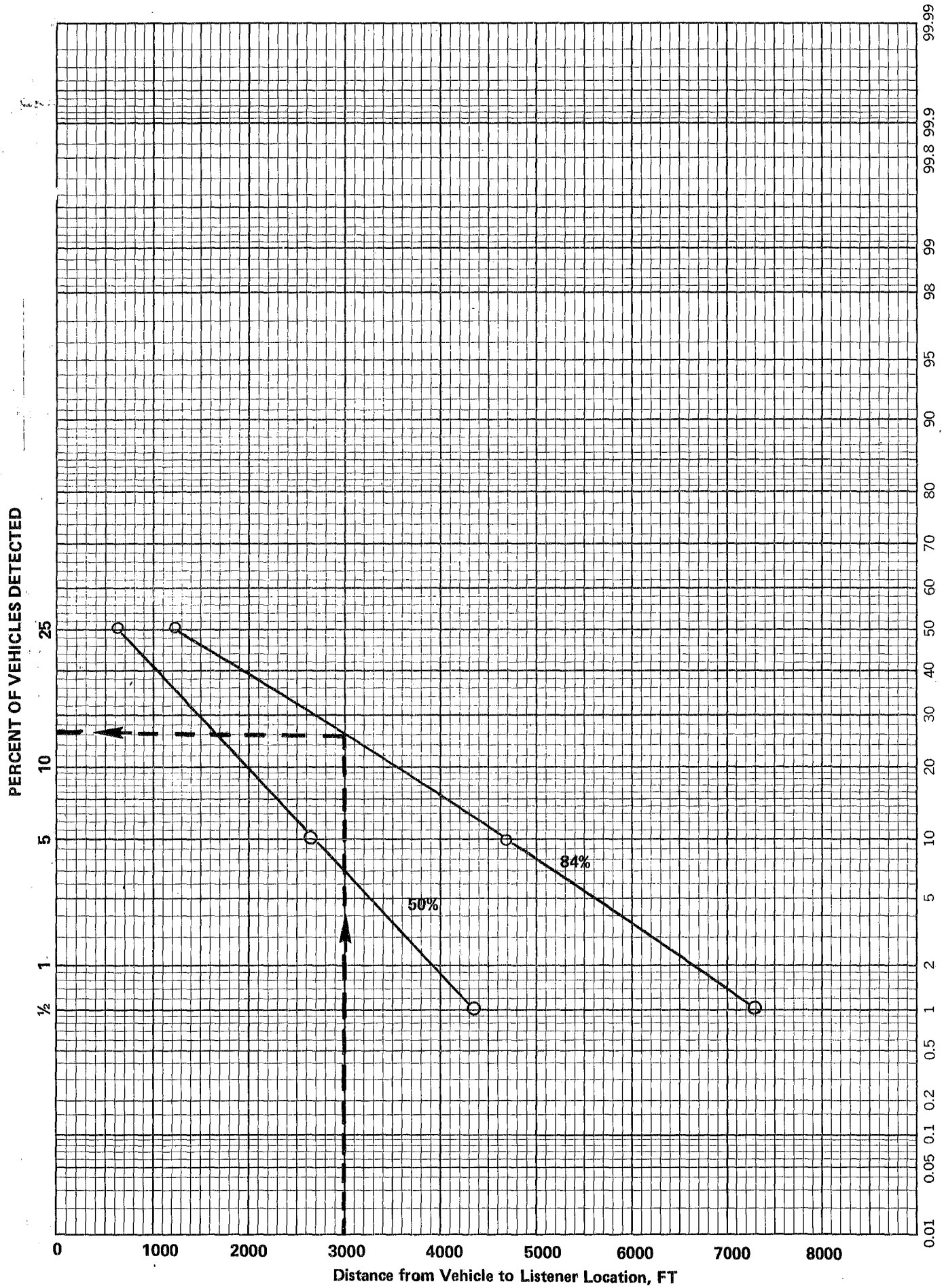

FIGURE A-9. DETECTABILITY--MOTORCYCLES.